Energy, Mines and Resources Canada | Energie, Mines et Ressources Canada

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Canada Centre for Mineral and Energy Technology | Centre canadien de la technologie des minéraux et de l'énergie

A PROPOSAL FOR A MAJOR RESEARCH PROJECT ON ROCKBURSTS

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MINING RESEARCH LABORATORIES

December 1984

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24 pp

MICROMEDIA

MINERAL RESEARCH PROGRAM
MINING RESEARCH LABORATORIES
DIVISION REPORT MRP/MRL 84-84 (TR)

90-03953/

A PROPOSAL FOR A MAJOR RESEARCH PROJECT ON ROCKBURSTS

by

John E. Udd*

ABSTRACT

Rockbursts, such as occur in the Canadian pre-Cambrian Shield, are attributed to stress redistributions which accompany mining in hard rock formations. Microseismic activity, which accompanies the stress increase preceding rockbursts, is viewed as having the potential to locate areas in which rockbursts may occur and, perhaps, to provide a means of short-term prediction prior to occurrence.

Although microseismic systems have been used experimentally in mines for many years, marginal advances in methodology and equipment development have limited their use. This is attributed in part to mine utilization philosophy, staff turnover, and the limited market for equipment which could be developed.

Source location is the objective of the existing, or planned, ten Canadian microseismic systems. The research on rockbursts which is proposed would involve investigation, development and testing of equipment and methodologies directed at improving the location of microseismic build-up, identifying the mechanisms of energy release, and, in some cases, warning of impending rockbursts.

The first phase of the proposed research would consist of three elements: studies at two Sudbury mines using extensive conventional state-of-the-art microseismic systems; studies with an advanced prototype system permitting detailed seismic event analysis at an important Ontario mine; and local area mine monitoring trials at several other small mines with a basic microseismic system.

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This proposed research on microseismic systems would be carried out over a five year period. Details on the proposal are provided in the text with respect to technical approach, research plan, specific objectives, benefits, cost, schedule and management structure. The total cost of the first phase, is estimated at $4,200,000.00.

The second phase of the work would involve trials to determine the effects of bulk mining methods, with various forms of backfill support, on local and regional stability conditions.

The cost of this second phase, involving bulk mining trials with associated microseismic monitoring, is estimated at $2,000,000. This phase would either follow the first, or would be commenced in the fourth or fifth year of it; depending on the development and availability of suitable monitoring systems.

The overall objectives of the proposed project are the following:

1. To improve the interpretation of microseismic signals, and the accuracies of determining microseismic source locations.
2. To improve evaluations of the effects of mining methods on local and regional stability conditions.
3. To develop leading-edge scientific capabilities in Canada, and to foster the spread of that technology through out the industry.

PROPOSITION D'UN PROJET PRINCIPAL DE RECHERCHE SUR LES COUPS DE TOIT

par

John E. Udd*

RÉSUMÉ

Les coups de toit tels qu'ils se produisent dans le Bouclier précambrien canadien, sont causés par la redistribution des contraintes associées à l'exploitation minière des formations de roche dure. L'activité microsismique qui accompagne une augmentation des contraintes avant les coups de toit, est perçue comme un moyen possible de repérer les zones où des coups de toit pourraient se produire et peut être même de les signaler à l'avance dans un court délai.

Bien que les systèmes microsismiques aient été utilisés expérimentalement dans les mines depuis de nombreuses années, le peu progrès dans le développement de l'équipement et de la méthodologie a limité l'utilisation de ces systèmes. Ceci est causé d'une part par la philosophie derrière l'exploitation minière, les changements de personnel et le marché restreint pour l'équipement qui pourrait être développé.

L'objectif des dix systèmes microsismiques canadiens actuels, ou projetés, est de localiser la source de l'activité microsismique. La recherche proposée sur les coups de toit porterait sur l'investigation, le développement et les essais d'équipement et de méthodologies dans le but d'améliorer le repérage d'une augmentation de l'activité microsismique, d'identifier les mécanismes des flux énergétiques et, dans certains cas, d'avertir de l'imminence des coups de toit.

La première phase du projet de recherche proposée comprendrait trois éléments soit: faire des études dans deux mines de Sudbury à l'aide de très gros systèmes microsismiques de pointe de modèle standard;

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faire des études à l'aide d'un prototype perfectionné d'un système de monitorage, permettant de faire une analyse détaillée des secousses sismiques dans une mine importante de l'Ontario; et enfin, de faire des essais locaux de surveillance de zone dans plusieurs autres petites mines, à l'aide d'un système microsismique de base.

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BACKGROUND

THE SIGNIFICANCE OF THE PROBLEM

A rockburst is a sudden, violent release of energy. It is a natural consequence of loading a hard, brittle, elastic material to the point of failure. Over the last two years, fourteen mines in Canada have experienced rockbursts.

A recent, and very tragic, event occurred in Canada at Falconbridge Limited's Falconbridge Mine (No. 5 Shaft), on June 20, 1984. In that instance a very severe rockburst caused the failure of the back (roof) of an undercut-and-fill stope. The resulting collapse of fill killed four miners. The long-lasting effects were the closure of the mine and the subsequent disruption to the work of some 400 men.

A further series of major seismic events, the largest of which attained a magnitude of 4.0 on the Richter scale, took place at Inco's Creighton Mine on July 6. Fortunately, a summer vacation shutdown was in effect at the time and no injury resulted from the damaged rock underground.

More recently, commencing on December 17, a series of rockbursts occurred in a burst-prone area of the Quirke Mine, in Elliot Lake. During the first two days of the renewed activity over 400 seismic events were detected. The largest of these attained a magnitude of 3.5 on the Richter scale. As happened on previous occasions, mechanics working in the area of the Denison number 1 shaft, some 500 meters away, expressed reservations about returning to work.

Because the effects of rockbursts can be devastating in both human and economic terms it is imperative that we use all of the means at our disposal to reduce the possibilities of the tragedies, injuries, and major dislocations that would be caused by other occurrences.

Fortunately, from a scientific point of view there is some promise that a solution can be found. In particular, the accurate determinations of locations of sources of microseismic occurrences may provide the key to both the locations of highly-stressed areas and the possibility of short-term prediction of events. Detailed analysis of wave forms may provide clues to the causes and mechanisms of rockbursts.

Microseismic emissions, which are usually in the ultra-sonic frequency range result from the propagation of cracks in brittle materials.

There is considerable evidence that the frequency of such microcracking increases as the level of applied stress is changed. Thus, the number of events may provide some measure of the level of stress which is applied.

In the laboratory, even when the samples of rock are very small, the cracking and the sudden explosion of a test sample can be impressive. In mines, the release of energy and cracking are on scales which are orders of magnitudes greater. For anyone who has experienced loud cracking or rockbursts underground, the effects are awesome.

STATUS OF CURRENT TECHNOLOGY

Unfortunately, very few advances have been made in application of microseismic technology to rockburst predictions. At present, after 40 years of equipment development and refining of techniques, there is still a large element of uncertainty in the handling of field data.

However, the reasons for this become more apparent. First, the scale of underground operations may be very large, thus necessitating major instrumentation programs with corresponding higher costs. Many companies, because of this, choose "target areas" for instrumenting - and in so doing, accept the risk that events may be outside of the sensor array. Such was the case with some of the recent rockbursts in Sudbury.

Second, in mining it is very common for individuals to progress rapidly through the managerial and technical ranks. Because of this, the experience gained by a skilled worker is easily lost through relocation or career progression. From a national point of view it is lamentable that there is a lack of microseismic specialists in mining. This situation is not likely to be rectified until specialists with the expertise have been developed and provided with the incentives to remain in the field.

Third, because experience in Canada has not been translated into a clearly applicable technology, microseismic equipment development has not paralleled equipment development in other fields. The market for microseismic equipment is very limited and there has been little financial incentive for manufacturers undertaking the essential technological developments in microelectronics or data processing.

Since field work began in the 1940's, a methodology based on geophysical techniques has been used. Geophones, arranged in a three-dimensional array to surround possible events, are used to detect signals. Because underground mines are often extensive, it can be appreciated that an array of any significant size can require miles of wiring. The times at which an event is detected at several geophones are used to calculate the original position of the disturbance.

In current practice the arrival of a first signal at any geophone in an array "opens a time window" for calculation purposes. The arrival of other pulses at a number of other geophones within prescribed time limits (as an example: at 5 geophones within about 50 milliseconds, or 1/20 second) is taken as confirming that a real event has happened within the volume enclosed by the array. The time interval selected is usually that which would be required for a sonic wave to pass through an array diagonally (i.e., the greatest distance between geophones). Having satisfied the criteria that an event is valid, the location is calculated from the arrival times. The use of arrival times at all of the geophones at which an event was detected, in various combinations, provides redundancy which is useful in assessing accuracy. After calculations, the original data is "dumped". This precludes any further analysis.

Unfortunately, geophones are indiscriminate. All sources of noise in a mine, therefore, may trigger the calculation sequence. Routine blasting, equipment operating, normal drilling, and even conversations may be detected by geophones. A large element of judgement is required in the selection of a "threshold value" below which events will not be recorded. No matter what level is selected, there will probably be legitimate events which will not be recorded.

At present, some 10 microseismic systems, with varying degrees of sophistication have been, or are being, installed in the following Canadian mines:

1.	Inco, Creighton Mine	64 sensors
2.	Falconbridge Mine	16 sensors
3.	Campbell Red Lake Mine	48 sensors
4.	Rio Algom, Quirke No. 2 Mine	24 sensors
5.	Potash Corp., Cory Mine	32 sensors
6.	Denison Mine	8 sensors

7.	East Malartic Mine	16 sensors (now removed)
8.	Rio Algom, Stanleigh Mine	16 sensors (planned)
9.	Lockerby Mine, Falconbridge Ltd.	32 sensors (planned)
10.	Brunswick, Noranda	32 sensors (planned)

All mine operators planning to install and use microseismic systems, however, are faced with essentially the same difficulties and problems. These were described as follows in a CANMET-sponsored workshop for industrial workers which was held in Sudbury, Ontario, on August 14-15, 1984 (note, a list of participants is attached as Appendix "A"):

1. There is a need for an approach, and system, which can be used to assess the influences of mining methods and practices. At present, microseismic monitoring is considered the best approach to large-scale or mine-wide monitoring (as opposed to local small-scale monitoring, which is used in conjunction with assessing the stabilities of individual stopes, or work places).
2. A difficulty with this approach is that microseismic activity begins to occur in hard and brittle rocks only when stresses have increased to the point at which failure begins to occur. Because the margin between the onset of seismic activity and a rockburst may be very narrow, the accuracies and sensitivities of systems are of great concern.
3. In the interest of improving the accuracy in both locating the sources (of events) and determining the energies involved, practitioners are looking for both improved equipment and practical techniques. The evaluations of equipment on a comparative basis (which has not yet been done, for cost reasons) might result in significant technical advances.
4. Equipment manufacturers should be encouraged to accelerate the development of "state-of-the-art" technology. This is difficult at present since the market is small.
5. Because of technical difficulties, the predictability of events is not feasible at present. While the locations of burst-prone areas can be established, warnings can not be provided of the timing's of probable events. Predictability in both time and space, however, must remain as a long-term goal.

TECHNICAL APPROACH

At present, the systems installed in Canadian mines involve a number of geophones and a processor. Analysis of data is based upon the time of first arrival of a seismic wave at each detector in the array. In general, the very first arrival of an event above a preset threshold value causes a "time window" to be opened. If a sufficient number of arrivals is detected by other geophones within the limits of the "time window" is is assumed that an event has occurred, and calculations are effected. A rapid series of events, however, such as those that occurred at Inco Metal's Creighton Mine on July 6, 1984, can be lost for purposes of recording and calculations. Because the system may be saturated with data, subsequent events may not be detected.

Historically, present systems have been developed from those which were used by mining engineers for detecting and locating single events. The development of equipment which can be used more successfully vis-a-vis multiple events is a matter of high priority.

With present systems only the channel numbers and the times of first arrivals are recorded. Significant improvements in accuracy, as regards event detection and source location, could be effected through waveform analyses. At present, any source which produces a noise above the threshold level (such as blasting, equipment operating, drilling) can cause a microseismic system to be activated.

The analysis of waveforms is considered to be the best approach to achieving differentiation between the causes of waves. If successful this would lead to considerable purification of data. This is also the only avenue of approach which would permit an assessment of source mechanisms for events. If successful in this respect, the resulting improvements in the sensitivities of systems would lead to a much greater understanding of the effects of mining on the surrounding rock mass. Fortunately, even though the approach recommended is more involved, microprocessing hardware is available which can be used to effect a very high degree of automation.

Also at present, it is common for the processing unit to be located underground, and the printer on the surface. Because of this the analogue signals are lost for purposes of further analysis.

In the present approach, then, it is proposed that the processing units be located on surface. While the primary function of the monitoring

systems will not be compromised, it will then be possible to do much more in the way of further analyses of signals. Analogue-to-digital conversions will be achieved by multi-channel interfaces on microcomputers. Filtering of extraneous interferences, alternative source location techniques, development of generalized event signatures, and the determination of the energies of various source mechanisms, are examples of further analyses that would be attempted. Sophisticated computer systems for signal and data analysis will be required.

As analytical techniques are developed at one or more central facilities, these will be implemented at the dedicated computer systems and the mines. The scheme will enable continual updating of monitoring techniques in the industry.

RESEARCH OBJECTIVES

The specific objectives of this proposed research project are the following:

1. To improve safety in underground mines.
2. To move closer towards the identification of areas or zones within mines in which seismic events (or rockbursts) are likely to occur.
3. To develop improved equipment and analytical techniques.
4. To increase an awareness in the industry of the effects of mining practices and sequences upon stabilities of the surrounding rock mass. This is particularly relevant to the newer large-scale bulk mining methods.
5. To increase Canadian capabilities in microseismic monitoring, and to develop a "National Centre of Excellence", in this respect, within the Mining Research Laboratories.

The achievement of these objectives will involve research:

6. To examine the waveforms of the signals resulting from a number of different, and known, events; with a view towards the recognition of characteristic event signatures.
7. To compare the signals originating in two distinctly different mining operations, with a view towards obtaining a better understanding of source mechanisms and of the differences (if any) between the resulting signals.

8. To develop methods by which extraneous signals may be removed from recorded data.
9. To effect improvements in the accuracy of determining the locations of events, and the energies released. The first questions asked by an operator after a seismic event are inevitably: "Where was it?", "How big was it?"

ANTICIPATED BENEFITS

If successful, this proposed research project will have the following potential benefits:

1. Result in increases in the sensitivities of microseismic monitoring systems, thus leading to a greater understanding of the effects of mining (and particularly those of large-scale bulk mining methods).
2. Through waveform analyses, result in improved accuracy in locating seismic events and the calculation of the energies involved.
3. Result in techniques by which the many interferences at present may be removed from the records and separated from the seismic data.
4. Result in a much greater understanding of the basic mechanisms and of the causes of rockbursts.
5. Lead towards the development of both improved equipment and techniques.
6. Represent a significant step forward towards the ultimate goal of being able to identify not only the areas in which rockbursts are likely to occur, but also, in as many cases as possible, to provide warnings.
7. Result in the development of Canadian expertise in microseismic monitoring and rockburst detection.

RESEARCH PLAN

RESEARCH DESIGN AND MILESTONES

The research program is comprised of three elements. These are:

(1) Detailed monitoring at two mines in Sudbury, Ontario.

(2) Evaluation of microseismic systems that are more sophisticated than those in Canada at present.

(3) Local monitoring trials in other mines.

(1) In the first of the elements it is proposed that both of the systems presently installed in mines in the Sudbury basin should be improved to reflect the best of "state-of-the-art" technology. In both cases the processing units are presently underground, and should be relocated on surface to permit the more sophisticated processing of data which are gathered. Computer systems, for on-site analyses of data, are also required,as are adequate on-line storage capabilities in order to prevent "buffer overloading" of the systems during a major event.

It is a particularly noteworthy feature of this element of the work that one of the systems to be upgraded is located in a mine which was recently closed after a series of major rockbursts. The second is located in what is probably the country's "flagship" nickel-copper mine.

At first glance, the above approach may seem to involve needless duplication. The scientific reasons, however, are compelling. These are:

1. The mechanisms causing rockbursts in each of the mines are believed to be different. In the case of the recently closed Falconbridge Mine, it is believed that slippage along faults was the basic mechanism. In the case of Inco's Creighton Mine, which also experienced severe bursting recently, it is believed that seismic activity was due to the breaking of rock during the propagation of a caving zone and the crushing of pillars.
2. In the case of the work proposed for the Falconbridge Mine, it should also be expected that results of a unique nature will be obtained. The mine, even though closed, will remain accessible as a route for the transportation of ore underground from the East Mine for possibly two years.

   In this instance, the work represents an unparalleled opportunity to obtain "pure" microseismic data against a background of no mining noise. Hopefully, any signals obtained will permit very precise analyses of the signature waveforms resulting from the fault-slip mechanism.

The milestones which would reflect progress in (1) would be:

1. The completion of the upgrading of both systems.
2. The obtaining of recognizable signature signals for each of the mechanisms causing rockbursts.

3. The relocation of the system at Falconbridge No.5 Shaft to another mine upon the successful conclusion of (2). (Note: this would be arranged by mutual consent as maintaining the system of No. 5 Shaft once the basic information sought has been obtained would serve no useful research purpose.)
4. The development of techniques which could be used to separate extraneous signals from legitimate microseismic data.
5. The demonstration that improved methods of determining locations and and calculating the energies involved have been achieved.

(2) In the second of the elements it is proposed that one of the more elaborate seismological systems which is available should be purchased and installed, for the purpose of making comparative evaluations, at Inco's Creighton Mine.

The particular feature of such systems that justifies a purchase is that each channel is equipped with a microprocessor (as opposed to one for an entire system). The net result is that analyses which reflect the highest degree of sophistication may be effected.

It is visualized that the results to be obtained, in waveform identification and the determination of sources, will be of a uniquely high quality.

The milestones, while very similar to those which would result from (1), and in fact, being complementary, would also include:

1. The installation and calibration of the seismological system.
2. The obtaining of recognizable waveform signatures which could be related to various events (including those caused by mining activities such as drilling and blasting).
3. The development of techniques for the "purification" of microseismic data.
4. Demonstrations that the techniques are resulting in improved accuracy.
5. The resulting up-grading at other operating Canadian mines.

(3) In the third element, a conventional microseismic monitoring system would be purchased and installed at mining operations, other than the two mentioned, for periods of up to two and a half years per installation.

Rockburst phenomena have also been experienced at several of the hardrock mines outside of the Sudbury area. Many of the companies involved do

not have microseismic systems because of both the costs and the specialized skills that are required. The objectives of this part of the work would be not only to assist other operations in the evaluation of the effects of local mining practices but also to gather additional field results which would add to the breadth of the overall study.

Initially, research would be concentrated on the problem of rockbursts in crown pillars of steeply-dipping narrow vein deposits (e.g., Campbell Red Lake, Dickenson, Macassa). This is the most common type of rockburst in Ontario. The research team would also investigate why rockbursts are rare in similar mines in the Timmins area.

The milestones which reflect progress would be individual reports in which the results of local studies would be given. These should appear at the rate of a least one per year.

ESTIMATED COSTS

The cost estimates which are given are based on the knowledge that a significant part of the expenses would be borne by the operations at which research would be conducted.

It is also certain that assistance would be received through collaboration with the Ministry of Labour of the Province of Ontario, and with other bodies (such as the United States Bureau of Mines).

To illustrate this point, the Ontario Ministry of Labour is also pursuing microseismic monitoring initiatives (for emergency preparedness purposes), and has generously offered to provide occasional use of office facilities, in Sudbury, and technical collaboration.

In the case of the studies in Sudbury, both Inco and Falconbridge have already invested in Electro-Lab Monitoring systems. Including the costs of equipment and installation, Inco has expended in excess of $200,000. Falconbridge, with a much smaller system has probably invested in the range of $100,000.

In the present proposal, it is assumed that the costs of new additional equipment, supplies, and the provision of some technical support, would be provided through federal and provincial contributions. The costs in respect of local installations of geophones and other units, and the provision of technical backup, would be provided by the individual companies participating in the project.

Thus with respect to element 1 the equipment costs are estimated to be:

(i) Upgrading Inco Creighton system

- Cable.....$ 40,000
- Electronics.....$ 25,000
- Computer system for data analysis.....$ 30,000

(ii) - Provision for computer to be used with Falconbridge system.....$ 30,000

- Subsequent expansion of system, up to full 64 channel capability, at another Falconbridge Mine, estimated at.....$100,000

Equipment costs for element 1 **$225,000**

With respect to element 2, the equipment costs are estimated to be:

(i) Seismological system.....$500,000

(ii) Data Processing Equipment and other Electronic Equipment for use with the above unit.....$300,000

Equipment costs for element 2 **$800,000**

With respect to element 3, the equipment costs are expected to be:

(i) Microseismic system with computer, for mine rockburst monitoring.....$ 75,000

(ii) Equipment for two to three installations ($100,000/installation).....$300,000

Equipment costs for element 3 **$375,000**

Total equipment costs **$1,400,000**

These costs are probably accurate to with about ten percent (1984 dollars)

To this, must be added the cost of technical support to be provided by CANMET. It is assumed that the team developed for this particular project would become members of the permanent staff complement - thus achieving the objective of developing a national centre of excellence.

The staff required, and the direct salary costs are estimated as follows:

(i) Seismologist.....$ 50,000/annum

(ii) Ground Control Eng.....$ 40,000/annum

(iii) Electronics Technician.....$ 35,000/annum

(iv) Support Technician, for field and workshop..$ 35,000/annum

(v) Secretarial and administrative support.....$ 20,000/annum

Direct Annual staff costs (excluding benefits) $ 180,000

CANMET staff cost for project $ 900,000

To the above CANMET project expenditure a sum of $40,000 per annum should be made available for travel and accommodation, and a further sum of $50,000 made available to cover the costs of staff hands-on training (in South Africa and in the Coeur d'Alene area of the United States of America).

Total CANMET travel and training and on-site accommodation costs for project.....$ 250,000

A further sum of $250,000 will be required for the replacement, maintenance and operation of portable (including mobile equipment). Audio-visual equipment to be used for technology transfer purposes, and costing approximately $15,000, is included in this estimate ..... $ 250,000

Total costs for staff, (excluding benefits) travel and training..... $1,400,000

During the project, both Inco and Falconbridge would each be expected to provide a full-time technician to the project, at estimated annual costs of $40,000 per company. A further amount, estimated at $1,000,000 would be required from these companies and others in the province, to cover part of the costs of local installations (including local living expenses). These potential contributions remain to be negotiated..... $1,400,000

Thus,

The grand total cost for the entire first phase of the project is estimated at..... $4,200,000

(being $1,400,000 each for: Equipment, staff, travel, training, installations).

The costs which are shown have been developed on the basis that other indirect, but substantial, contributions to the project would be made by the industry. An actual value cannot be assigned to these at present.

WORK PLAN: Phase 2

Finally, as mentioned, it is recommended that the first phase of the work, as described previously, should be followed by a second phase involving studies of the effects on stability of bulk mining methods (with various filling alternatives). From this perspective, some five years in advance, it is not possible to establish a budget for this aspect of the work. Nonetheless, a preliminary rough estimate of $2,000,000 is not considered to be unreasonable.

WORK PLAN. Year 1

During the first year of the project, the equipment for the upgrading of the system at the Creighton Mine would be purchased and installed. At the same time, the Falconbridge system would be improved through the addition of an on-site computer.

By the end of the first year the project team should have been recruited and appointed. Either the seismologist or the ground control engineer should have received foreign hands-on training in the use of systems elsewhere (or should be close to the completion of that training - estimated at 6 months). A visiting scientist should have been appointed to CANMET on a sabattical basis and would be in the process of training and advising local staff.

Because no major modifications, apart from the installation of a computer and the relocation of the processor - from underground to surface - would have been made at the Falconbridge No. 5 Mine, it is expected that the results determined by the end of the first year would very nearly satisfy the original requirements for "pure" signals.

A study of rockbursts in crown pillars, at a mine at which a system is presently installed, would also be initiated as a separate, but related project during the first year.

WORK PLAN: Year 2

By the end of the second year the work at the Falconbridge Mine should have been completed. Afterwards, by mutual agreement, as much of the system as possible could be moved to another mine in the Falconbridge group.

The work at Inco's Creighton Mine would have progressed to the point at which at least some individual signature signals could be identified. The work, in respect of purification of data, should be well advanced.

Simultaneously, the conventional rockburst monitoring system would have been purchased and installed at a specific site.

At the end of the second year, all of the equipment required should have been installed in place and successfully calibrated and made fully operational.

WORK PLAN: Years 3 and 4

During the third and fourth years of the project, the major effort in connection with event recognition would be continued at the Creighton Mine while other case-history studies would be underway at other locations.

Following the establishment of precise specifications, the more sophisticated monitoring system would probably be ordered and installed during the third year.

Monitoring could be continued at the Falconbridge property into which the equipment had been relocated during the second year of the project. At the end of the fourth year of the research it would become clear if further extensions to that system might be required.

WORK PLAN: Year 5

During the final year of the work for this project it is anticipated that the original objective would have been met and that objectives and a plan for on-going studies would be in a stage of development by the project team.

As mentioned previously, it has been suggested that it would be logical for the work to be continued through assessments of the effects of bulk mining methods on local stability conditions. Trials, if not actually underway at this stage (as the result of an agreed-upon acceleration of the work), would at least be at an advanced stage of planning.

With mining at Creighton being likely to continue well into the next century, and with conditions likely to become more difficult at depth, it is probable that the increase in microseismic activity which is anticipated would also result in plans to continue the original work. While it is hoped that a number of the technical problems would have been solved, the aspect of predictability would probably remain as a high-priority key issue.

CONTINUATION PLAN: Subsequent Years

At the end of the five-year period, a well-qualified team with considerable experience in both rockbursts and microseismicity would have been

developed in CANMET/MRL. Because it is certain that rockbursting problems must become more acute as Canadian mining progresses to greater depths and extraction ratios there is no doubt that continuing activity at a high level will be required.

During the next five years it is also likely that increased use will be made of low-cost bulk mining methods in order to effect productivity improvements - which will be necessary to the survival of the industry. The effects of large scale mining on regional stability conditions are not fully known and, consequently, local monitoring will be essential.

With both of the above in mind, then, the steps which have been proposed towards the development of a Canadian expertise will undoubtedly be shown to have been in the national interest.

LIAISON WITH OTHER ORGANIZATIONS

A close technical liaison will be maintained with the Seismology Division, Earth Physics Branch, EMR, which operates the Eastern Canada Seismic Network. Any large rockburst saturates mine microseismic networks, and data acquired through the national seismic network is required for the calculation of magnitude values. It is also visualized that the Earth Physics Branch will be requested to provide analytical assistance.

Close liaison at the working level will be maintained with the Mining Health and Safety Branch of the Ontario Ministry of Labour. That Branch has taken a leading role in advocating the development of monitoring systems in Ontario mines during the past five years, and is involved with rockbursting problems on a daily basis. Their participation is unquestionably "key" to the success of the project.

Regular contacts will be also established with research organizations working on rockbursts in other countries, noteably the Chamber of Mines in South Africa and the United States Bureau of Mines. It is also hoped that it may be possible to conclude a joint USBM/CANMET/MOL agreement for the sharing of research results in both ground control and emergency preparedness measures in the near future. Similar agreements already exist in other areas; notably for wire ropes and for diesel emissions.

TECHNOLOGY TRANSFER

Starting in the 2nd or 3rd year of the project, workshops and seminars will be held in the various mining camps. The latest research

results will be explained to the industry, regulatory agencies and other interested organizations. At the end of the 5th year a manual on rockbursts will be prepared.

CO-ORDINATION AND DIRECTION

During the initial stages, in which the project team would be formed, both co-ordination and direction would be provided by a CANMET/MRL team consisting of:

Dr. D. Hedley, Research Scientist, ELL

Mr. G. Larocque, Manager, RML

Dr. J.E. Udd, Director, MRL

In the very first stages, the work would consist of the ordering and installation of the equipment required. This would be well within the capabilities of the above team.

Additionally, there would be a continuing dialogue with the industrial partners and it might be desirable at an early stage to ask each company participating to provide a representation to sit on an overall steering committee.

With the development of the project team, however, co-ordination of the work would be assumed by this group - which would be situated at the Elliot Lake Laboratory of MRL.

Overall direction would continue to be provided by the original team, to which the professionals working on the project would have been added. Representation would also be sought from other organizations participating in the project, such as: the Ontario Ministry of Labour, INCO, Falconbridge, etc.

APPENDIX "A"

The following is a list of the participants at a CANMET-sponsored workshop "Microseismic Monitoring in Canadian Mines", held in Sudbury, Ontario, on August 14-15, 1984.

Chris Page	Johannesburg, South Africa.
Tony Makuch	Campbell Red Lake Mines, Balmertown, Ontario.
James Willan	McGill University.
Hamish Miller	University of British Columbia, Vancouver.
Dave West	Falconbridge Ltd., Falconbridge, Ontario.
Barbara Welsh	Dickenson Mines, Balmertown.
Ian Clegg	Falconbridge, Ontario.
Ed Berdusco	Algoma Ore Division, Wawa.
Alex Henderson	Lockerby Mine, Falconbridge Ltd.
Jacques Bourbonnais	Roctest Ltd., St. Lambert, P.Q.
John Cook	Lac Minerals, Kirkland Lake, Ont.
Don Bruce	Lac Macassa, Kirland Lake, Ont.
Akbar Sheikh	Denison Mines, Elliot Lake, Ont.
G. Hunt	Denison Mines, Elliot Lake, Ont.
Jim Chandra	Dept. Natural Resources, Fredericton, N.B.
F. Umangay, Jr.	Elliot Lake, Ontario.
P. Oliver	Inco Ltd., Copper Cliff, Ont.
J.A. St. Pierre	Falconbridge Ltd.
H.A. Smith	Falconbridge Ltd.
R.A. Cameron	Laurentian University, Sudbury, Ont.
Frank Ingham	Rio Algom, Elliot Lake, Ont.
Gary Morgan	Rio Algom, Elliot Lake, Ont.
Peter Cain	CANMET/CRL - Cape Breton, Sydney, N.S.
Tom Vladut	CANMET/CRL - Calgary, Alberta.
Charles Graham	Sudbury, Ontario.
Thian Yu	Kidd Creek Mines, Timmins, Ont.
Harald Kanduth	Noranda Research Centre, Pointe Claire, P.Q.
Osman Momoh	Noranda Research Centre, Pointe Claire, P.Q.
Corwin Malott	Electro Lab, Spokane, Washington
Jim Vance	PCS Mining, Saskatoon, Sask.
John Udd	CANMET/MRL, Ottawa, Ontario.
Glen Larocque	CANMET/MRL, Ottawa, Ontario.
Paul MacDonald	CANMET/MRL, Elliot Lake, Ontario.

APPENDIX "B"

Estimated Expenditures by Years

	YEARS			
1	2	3	4	5
A) Equipment, $1.4 Million (refer to page 11)				
$300,000 up-grading INCO and Falconbridge systems	$200,000 * purchase of a standard system (*includes $100,000 for local installation)	$700,000 * purchase of precision system	$100,000 costs of local installations	$100,000
B) Human Resources, and equipment maintainance, $1.4 Million (refer to pages 11-12)				
i) Manpower				
2 PY	3 PY	5 PY	5 PY	5 PY
$100,000	$125,000	$225,000	$225,000	$225,000
ii) Travel				
$40,000	$40,000	$40,000	$40,000	$40,000
iii) Training				
$25,000	$25,000	---	---	---
iv) Maintenance and contracts for local installations				
$50,000	$50,000	$50,000	$50,000	$50,000
C) Industrial Contributions to support local installations, $1.4 Million (refer to page 12)				
i) Manpower				
2 PY	2 PY	2 PY	2 PY	2 PY
$80,000	$80,000	$80,000	$80,000	$80,000
ii) Contributions to cost of project (labour, use of systems, materials)				
$200,000	$200,000	$200,000	$200,000	$200,000